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THE ORIGIN OF THE ALPS.*

BY

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Geography is based on exploration and investigation. No less necessary than the work of the pioneer, who penetrates into unknown countries, is the work of the scientist who studies minutely a more limited region and tries to clear up certain scientific questions.

While in the interior of Africa and Asia and the Polar regions of both hemispheres international geographical explorations were going on, the Alps were the chief field of geographical research in Europe, and most new ideas on the origin of mountains have arisen there or have been proved there. Half a century ago it was believed that the Alps were formed by a vertical upheaval. It was imagined that the rocks which form the axis of the mountain range came as an eruptive rock from the interior of the earth and that they pressed together the layers deposited along the sides of that region where they were intruded. But later we learned that the Alps were formed by folding of the strata caused by lateral compression of the crust of a shrinking globe, which shrinking was believed to be the result of a loss of heat. Indeed, there are regions in the Alps where we can see a very clear crumpling of the strata. Every visitor to the Lake of Lucerne knows how the strata along the Axen-Strasse are folded and compressed, and every visitor to the Säntis Chain knows the remarkable anticline which forms Mt. Säntis and has also seen the synclines of the neighbouring valleys.

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* An Abstract of a Lecture before the American Geographical Society on Nov. 24, 1908.

One of the most eminent geologists of Switzerland, Arnold Escher von der Linth, pointed out this system of anticlines and synclines, which is, indeed, of astonishing perfection. We find here the layers of the lower, middle, and upper Cretaceous forming a system of folds, and these folds rise from a country in which are younger deposits of early Tertiary age. It was believed by Escher von der Linth that these Cretaceous layers were pressed up amid the older Tertiary deposits. A recent investigation of the chain, however, has convinced Albert Heim that these older layers are not pressed upward from beneath the younger ones, but that they are pushed over them, and that all those wonderful folds of the Säntis Chain are merely afloat on the younger rocks. This mountain chain has no roots in the crust of the earth. Its whole mass has been transported.

This new explanation is coincident with the new ideas on the formation of Alpine structure, and these ideas have been formed step by step. The first decided step was made by Albert Heim who showed us that in very extensive parts of the Glarnese Alps older strata are found above younger ones. He thought at first, as did his master, Escher von der Linth, that these phenomena must be explained by the assumption of a double fold of rocks, one pushed from the north and the other from the south, by which movement older strata were forced above younger ones. But Marcel Bertrand showed that there was another explanation possible, which assumes only one fold which was thrust over a region of considerable width. This idea of Marcel Bertrand did not attract much attention in the beginning, but later the researches of Hans Schardt in the region of the upper end of Lake Geneva, which were confirmed by those of Lugeon, have demonstrated that the conception of Bertrand on the structure of the western Alps was right, as it was always believed to be by Eduard Suess. In consequence, Heim adopted it for the Glarnese Alps.

Now we know that the chains of the Alps are only partly formed by material which is at present at the place where it was deposited and where it is pressed together as if in a vice. Only a part of the mountains is autochthonous; the whole border of the Swiss Alps from the Valley of the Rhine to the Valley of the Rhone is allochthonous. That is, the chains consist of layers which have been deposited farther south than the regions in which they are found.

We can distinguish in the border region of the Alps of Switzerland three different overthrust layers, lying one above the other and all upon an autochthonous substratum of older Tertiary deposits. We see at first material, which can be derived from the north side of the Swiss Alps, forming the so-called Helvetian thrust layer. Above this we find the thrust layer of the Klippen, the origin of which lies in the central zone of the Alps. Above that we meet with a third thrust layer, the material of which comes from the south side of the Alps, and that is the so-called East Alpine thrust layer.

Every thrust layer consists of a set of folds which are thickest and very much pressed together just at the outer edge of the layer, where they form enormous, flat-lying folds. Only in a few cases is it possible to trace back the overthrust layers to their roots. As a rule, this connection cannot be followed, and it is only by the position of the overthrust layers that we can judge as to the places of their probable derivation.

Such an arrangement is not consistent with the idea that the folds of the Alps were made directly by lateral pressure. This whole condition reminds one of material which has slid down, as, for example, the material of a landslide. Such material, indeed, forms an arrangement similar to a thrust layer. It is very much pressed together at its outer edge, and several writers have suggested that these thrust layers were moved under the influence of gravity which caused a downward movement of materials, which, for some reason—probably through strong lateral compression—became over-elevated so that they could not stand and consequently flowed down.

As a consequence of these ideas, we have to assume that, at those regions where we to-day find the thrust layers, formerly a depression existed into which the material could slide down, and that, instead of the high border ranges of the Alps from the Säntis over the Glärnisch to the Diablerets, a low ground extended into which the different thrust layers moved down and which later became elevated. Thus we become aware that the folding of the strata is not the direct cause of the present mountain range but that the latter came into existence later by elevation. Indeed, there are very extensive tracts in the Alps which are very high but which are not folded at all. We think here of the well-known Dolomite region of Southern Tyrol. Here we find horizontal layers of Permian and Triassic age forming mountains the height of which varies from 9,000 to 10,000 feet, and which are often covered with glaciers.

We have distinct proof in the structure of these mountain ranges that folding is not the necessary corollary of mountain-making even in the Alps and that the more elevated parts of the Alps owe their height to a vertical movement of the earth's crust in the same way as the plateau of Colorado. Indeed, there is a remarkable similarity in the structure of the southeastern Alps and that plateau. The difference consists only in the amount of dissection. The Colorado plateau is only cut through by a river and the highland still stands nearly untouched. In the southeastern Alps, however, the plateau is almost totally destroyed and only pillars of material remain which indicate its former height.

Recent investigations have shown that the vertical movement which caused the elevation of the Alps is still going on and that it was very considerable even in the last geological period, that is, in the Quarternary or Pleistocene.* These proofs are given by the surface features of the mountains. We can trace in our deep Alpine valleys terraces of rock which indicate older valley floors. These valley floors do not have that slope which is characteristic of river valleys. This slope is rather slight in the interior of the mountains, and it becomes pretty steep at the edge of the Alps. This arrangement indicates a general upheaval of the Alps which was felt most strongly just at the border of the mountain chain.

A very important feature in the main valleys of the Alps proves the continuity of their elevation until very recent times. We find now and then deposits of former lakes which were ancestors of the lakes of to-day, but the deposits lie far higher than a lake could exist to-day. The repeated recurrence of these facts points to a general cause which we assume consists in an elevation of the Alps with the lake deposits in their valleys above the surrounding country.

The mountain region which had just been elevated had some other surface features than the Alps of to-day. The mountains were not so high; their forms were more rounded; their valleys were broader and not so deep as to-day. The whole surface of that mountain region was in a state of orographic maturity. At the northeast end of the Alps, especially in Styria, these mature surface features still exist. At other places they are dissected by very deep valleys. Thus, for example, in the southernmost parts of the Tyrol west of Lake Garda and southeast of Trient. Here the highlands have the soft rounded forms of a mature landscape. Those mountainous parts are separated from each other by valleys with very steep slopes. The slopes are evidently cut into the older formations. Even in the interior of the mountain chain we find remnants of its former maturity. We meet with very broad valleys and mountains, the general outline of which is a rolling one. Even the chain of the Mont Blanc conserves features which indicate that the chain was formerly rounded.

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* A detailed description of the corresponding facts is given by the author and Ed. Brückner in: Die Alpen im Eisseitalter, Leipzig, 1909.

We must expect, indeed, that a region which becomes elevated above the surrounding country will have a kind of rejuvenation of its forms. Its rivers must begin to erode deep channels into their former valleys. But the rejuvenation of the Alps is only partly due to river action. It is for the larger part caused by ice. During the great Ice Age the Alps were four times covered with a vast mantle of ice, and the very glaciers which filled up the valleys have left everywhere the traces of their former existence. They eroded the valleys in a very characteristic way, giving them U-shaped cross sections. The larger the glaciers, the deeper were the valleys eroded. The larger valleys became far deeper than the smaller ones. They are over-deepened; the smaller are hanging at their sides. We do not find in the Alps that regular joining of river floors which corresponds to the law of Playfair and which is so characteristic of valleys excavated by water. The law of Playfair, which applies to the formation of true river valleys, is not valid in the Alps with the exception of those parts which have not suffered from the glacial action; namely, those parts lying in the northeast corner of the mountain chain. Here we find numerous river joinings at grade and, as already mentioned, between them rounded mountain forms. Everywhere we have to deal here with true orographical maturity, in the words of William M. Davis.

Where the main Alpine valleys show the characteristic over-deepening and the lateral valleys are hanging along their sides, the lateral affluents of the main rivers either come down in waterfalls or in narrow gorges which they have excavated, just in the step which separates the floor of the over-deepened main valley from that of the hanging valley. In these gorges we find the finest display of river action one can imagine. The water rushes down, whirling out pot-holes, foaming over ledges. Here are the places where we can study water erosion. Water, however, does not erode in the over-deepened valleys, but deposits there the material it carries along with it in the form of enormous alluvial fans. Thus deposition occurs to-day where the glaciers have exercised their strongest erosion, and, on the other hand, the river action in the Alps is most conspicuous at places where glacial erosion has been least.

The over-deepening of the main valleys extends as far as the old glaciers reached. At the end of the glaciation the bottom of the over-deepened valley gently rises to the level of the pre-glacial valley floor. Thus concave forms in the over-deepened valleys come into existence which are partly occupied by lakes and partly filled out by later river deposits. All large lakes in the Alps lie near the end of the old glaciers and most of them are surrounded by important terminal moraines of the old glaciers. A few, however, do not reach as far as the ice extended, and occupy regions where the over-deepening of the valleys by the glaciers ceased from other causes. All great Alpine lake-basins, however, have been eroded by the ice, though some of them are partly dammed up by the moraines just at their end.

It is also due to the existence of former glaciers that the mountains of the Alps have lost their rounded forms. Glaciers have gnawed into these mountains. They have excavated those interesting forms which are called "corries" in Scotland, or "cwmbs" in Wales, or cirques in North America. These are the "kare" of the Alps. These kare have been compared to armchairs. Their flat bottom is surrounded on three sides by steep walls and in several groups of the Alps we can still follow the original rounded surface between the kare, but in other ranges these kare become so large that the steep walls of neighbouring and opposite kare meet together, forming a sharp crest-like ridge. These ridges are the characteristic feature of the high parts of the Alps. In the very high parts they divide glaciers from each other which are still continuing the deepening of the kare. At those heights which have already lost their glaciers, they form the surroundings of little lakes which are found on the floor of old, small glaciers, as the big lakes on the floor of the larger glaciers. In many parts of the Alps neighbouring kare unite and their bottoms join together to form a terrace above the over-deepened part of the valley. At those places there is a regular succession of forms; the U-shaped bed of the main glacier, the steep slopes, and above those slopes a shoulder on which were lying the lateral affluents.

The Alps as they are to-day are only the ruin of what they formerly were. Their surface is not at all as it was once believed to be, a direct result of crustal movements which split asunder the mountains and formed the valleys as crevasses. The highest parts are not those which have been elevated highest, but they consist mostly of the hardest material which offered the greatest resistance to weathering. The valleys are, however, the work of rivers and are modified very much by ice. The elevation of the mountains is not the direct result of a folding of the strata, but of a recent uplift which occurred over a zone of central Europe which had only partly a very complicated structure and which, on the other hand, had a very simple structure, and which before its elevation had rounded mountains and well-graded valleys.

The complicated structure, which is best seen along the north side of the Alps, can be regarded as a consequence of enormous fundamental folding by which one part of the Alps became very much elevated, probably as a result of compression, while the neighbouring part sank down. And, as in the over-deepened valleys of to-day, we now and then meet with considerable mountain-slides, those parts of the over-elevated fold seem to have slipped down into the sunken part of the fold. We now and then meet on the floor of the ocean forms which remind us of such fundamental folds. There are very deep troughs outside of islands, and between the islands and the troughs we encounter very steep slopes on which our telegraph cables are often torn asunder, a fact which has been repeatedly ascribed to local slides occurring here. There are, indeed, some reasons to believe that the folding of the strata of the Alps had something to do with the formation of a deep trough on the earth's crust. Their strata exhibit often far greater thickness than we see elsewhere, and their character differs pretty much from that of the surrounding layers. But the reconstruction of the geographical features of the unfolded region met with one difficulty; that is, layers which were formed under very different geographical conditions are found in the adjoining regions, a fact which is easily explained by the assumption of the very considerable overthrusts which occurred. These overthrusts could not have occurred at the surface of the earth, and, if we find the relics of thrust layers confined to small mountains, as, for example, Mythen near Lake Lucerne, then we become aware of the enormous amount of erosion which has lowered the Alps. But this erosion has been counteracted by a recent uplift.

Thus the origin of the Alps is a very complicated one, and, although much has been added to its history during recent years, still many problems remain to be solved.